Vertical Structure in the Water Column: Implications for Bio-Optics and Remote Sensing

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LONG-TERM GOAL

The long-term goal of this study is to examine the vertical structure in bio-optical properties and to classify features that persist at large scales, particularly with a view to application in remote sensing of the underwater light field and of the water-column primary productivity at basin to global scales.

SCIENTIFIC OBJECTIVES

In the present proposal, we emphasise issues related to the vertical structure of the water column: (1) the use of coupled models to improve our understanding of the vertical structure of the water column, and (2) the use of information other than just chlorophyll-a to refine optical models. The work will be oriented towards examining the implications of vertical structure for penetration of light underwater and for remote sensing of primary production. The main objectives of the study are then:

1. To explore the use of models that couple bio-optical models with models of physical processes to improve our understanding of the vertical structure in the bio-optical properties of the euphotic zone.

2. To examine whether and how models of light transmission underwater and of ocean colour can be improved by incorporating explicitly the influence of other material in addition to chlorophyll-a.

APPROACH

The technical approach will be to treat theoretical model developments and in situ and laboratory experiments as complementary tools:

1) In situ measurements of bio-optical properties will be made in diverse environments, with emphasis on data collection from contrasting environments: open-ocean versus coastal waters, oligotrophic versus eutrophic waters. Regional emphasis for ship-board measurements will be the N. Atlantic and the Arabian Sea.

2) The in situ experimental program will be supplemented by laboratory experiments on optical properties of phytoplankton and other substances.

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3) Development of improved optical models for light transmission and ocean colour, incorporating explicitly the role of substances other than chlorophyll-a, is envisaged.

4) The bio-optical models will be coupled to dynamic models of the upper ocean to improve our understanding of vertical structure in bio-optical properties.

WORK COMPLETED

Over the last several years, we have been collecting data on phytoplankton absorption spectra and on HPLC pigment concentrations, sometimes from several cruises in each year. All these data have now been analysed, quality checked, and archived. Our data set for the low and mid latitudes (from the North Atlantic, South Eastern Pacific, eastern and western Canadian coastal waters, the Arabian Sea) amount to over 700 samples. In addition, we have over 100 samples from a high-latitude environment (exclusively from the Labrador Sea). This forms an excellent data set from a number of environments, ranging from oligotrophic waters in the Arabian Sea dominated by prochlorophytes and cyanobacteria, to productive waters of the Labrador Sea, sometimes dominated by blooms of diatoms or prymnesiophytes. We have now begun to exploit this data set in the interpretation and application of ocean-colour data (see Results, below).

Bio-optical data (photosynthesis-irradiance parameters, phytoplankton absorption spectra, HPLC pigment concentrations) were collected during three cruises in 1998: an April cruise to the Scotian Shelf, a June cruise to the Labrador Sea, and an October cruise to the Scotian Shelf.

RESULTS

1. Differences between *in vivo* absorption spectra and fluorescence excitation spectra of natural phytoplankton populations

Absorption spectra and fluorescence excitation spectra were measured during two cruises: one a trans-Atlantic cruise from Nova Scotia to the Canary Islands, and the second one a spring cruise during which data were collected on the Newfoundland Shelf, and along a transect from Greenland to Southern Labrador. Comparison of the two spectra showed that there were significant differences between their shapes in the blue part of the spectrum. The data were interpreted using information on the pigment composition of the samples, determined using HPLC analyses, which suggested that the differences were not always attributable to the presence of photoprotective carotenoids. It is likely that some of the differences are due to differences in the patterns of energy distribution in the photosystems of various algal groups. This is part of the Doctoral thesis work of Vivian Lutz. A paper has been published in the *Journal of Phycology* (Lutz *et al*. 1998). This work has been supplemented by laboratory measurements on phytoplankton cultures, which shows that, in the case of cyanophytes, the differences between absorption and fluorescence spectra are enhanced due to differences in the structure and function of the photosystems. The results are to be presented at Ocean Optics XIV in Hawaii, November 1998.

2. Remote sensing of phytoplankton in waters off Vancouver Island

A remote sensing experiment was carried out in the waters off Vancouver Island in which mulitspectral, water-leaving radiances were measured from an aircraft using a Compact Airborne Spectrographic Imager (CASI). Concurrent measurements of phytoplankton pigments and phytoplankton absorption were made on samples collected from boats. The atmospherically-corrected water-leaving radiances are in general in good agreement with modelled reflectances computed using a theoretical reflectance model implemented using the local measurements for phytoplankton absorption. However, the spectra of the ratio of modelled reflectance to measured water-leaving radiance had slopes that differed from zero.

These slopes were seen to be related to changes in the concentration of dissolved organic carbon (DIC) relative to chlorophyll-a concentration. In these DOC-rich waters, algorithms that avoided blue wavelengths performed better at mapping the pigment concentration than often-used algorithms that use blue wavelengths. Fluorescence-based algorithms and absorption-based algorithms for mapping chlorophyll-a distribution in the waters around Vancouver Island showed pigment concentrations in similar ranges, but there were also differences between them. A manuscript is in preparation.

3. Analytic algorithms for retrieval of chlorophyll-a from low-latitude waters

Over the last several years, we have been making measurements of phytoplankton absorption and pigment concentrations. These data have now been compiled, and used to implement an ocean-colour model for interpretation of satellite data. The results show excellent agreement with empirical algorithms in use today for retrieval of pigment concentrations from CZCS, OCTS and SeaWiFS data. Our results also suggest that there may be significant decrease in the accuracy of these algorithms in the presence of some diatoms blooms, arising from differences in their absorption characteristics. Two papers will be presented on this topic at the Ocean Optics XIV symposium in Hawaii this November.

4. Analytic model of the influence of chlorophyll-a fluorescence on reflectance spectra

Recently, we developed a simple model for incorporation of Raman scattering into ocean-colour models. This work has now been extended to include chlorophyll-a fluorescence in the red part of the spectrum, in collaboration with Prof. Kanthi Yapa, from the University of Ruhuna, Sri Lanka. The initial results will be presented at the Ocean Optics XIV symposium in Hawaii this November.

5. Primary production in the Arabian Sea

In collaboration with the University of Newcastle, UK (Dr. Louisa Watts, Prof. N. P. J. Owens), primary production and new production have been computed for the Arabian Sea. The approach is similar to our earlier approaches, in that primary production is computed using photosynthesis-irradiance parameters and a spectral light transmission model. However, these computations represent some significant improvements: 1) The parameters of photosynthesis-irradiance curves, and the parameters of light transmission have been improved, using data collected during JGOFS cruises. 2) The biogeochemical provinces have been implemented on a dynamic basis, with movable boundaries, and the extent of the provinces has been determined using satellite data. 3) The calculations have been extended to include new production, using local relationships between f-ratio and total production. A manuscript based on this work has been submitted *to Marine Ecology Progress Series.*

IMPACT/APPLICATIONS

The results reported here on the bio-optical properties of phytoplankton are relevant to developing regional optical models of light transmission in the ocean, and of ocean colour, for applications in remote sensing of primary production at large scales. The optical models that we have developed in this connection are formulated such that they can use the observations of these properties directly as model inputs.

TRANSITIONS

The Applied Physics Laboratory of the Johns Hopkins University has shown an interest in using our chlorophyll profile data base and the bio-geochemical provinces for their LWR environmental data base. This has been mutually beneficial. The comparisons between our model predictions, and the optical data base of Jeff Smart has suggested some improvements to our modelling effort. Scientists from the Plymouth Marine Lab (UK), the Instituto Canario de Ciencias Marinas (Canary Islands, Spain) have also shown an interest in the bio-geochemical provinces data base. The Joint Research Centre at Ispra has shown an interest in using our ocean-colour model for remote-sensing applications.

RELATED PROJECTS

Related projects are the NSERC (Canada) research grants held by Sathyendranath and Platt. The NSERC project of Platt deals with the formation of phytoplankton blooms, whereas the NSERC grant to Sathyendranath supports ocean colour work in coastal waters. The grants are primarily for supporting post-graduate students and technical staff who contribute to the work reported here.

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